Additional Design Constraints

- Besides design specifications driven by physics and Main Injector beam parameters, significant design constraints for the NuMI primary beam are given by:
  - Facility Construction
  - Radiation Control
  - Instrumentation Requirements
  - Precision Beam Control
  - Cost Efficiency
- While not as fundamental - in initial perspective - as those for physics and beam source, these dominate much of the primary beam system design.

Facility Construction Impact

- NuMI target hall facility construction approach was chosen (for cost efficiency and surface footprint constraints) as a deep cavern - upstream floor level ~ 140 feet below grade.
  - This enables mining of the pre-target and target hall while maintaining a viable structural ceiling of rock.
- Also, the primary beam transport through the glacial till / rock interface region - where the medium does not provide structural support - should be as short as feasible, and in a small diameter enclosure.
  - This leads to a steep down-bend from MI level of 156 mrad, followed by **up-**bend of 98 mrad in pre-target enclosure to achieve final 58 mrad down-bend for targeting.
  - Construction cost constraints for carrier tunnel through interface region dictate that this is **not** a normal accessible enclosure. This produces a requirement for a > 400 ft. drift region without quadrupoles.

Radiation Control: Groundwater Protection

- NuMI requirements are for a very large fraction of the available Main Injector intensity over a period of several years. For each MI accelerator cycle, 5 of 6 batches will be sent to NuMI.
- Transport of this intense beam is in a tunnel located in the protected groundwater aquifer region.
- Shielding of the primary beam transport, as is done for the target hall, would be cost prohibitive.

- These constraints lead to a requirement for rigorous monitoring and control of beam loss during primary transport. Presentation by N. Grossman.

Radiation Control: Residual Activity

- Primary beam cleanliness requirements for groundwater control are consistent with those also needed to control levels of residual activity:
  - MARS calculations by S. Striganov indicate that a sustained localized fractional beam loss of $1\cdot10^{-4}$ can produce residual activity levels reaching several hundred mrem/hr.
  - The impact of a 3 mil Titanium window, with $\lambda/\lambda_0 = 2.8\text{x}10^{-4}$, would be residual activity levels on the surface of a near downstream magnet of > 500 mrem/hr.

- During operation for the TeV experiment, E-815, a magnet vacuum chamber was destroyed by mis-steered primary beam, with each 800 GeV machine cycle providing 5 pings of 2E12 protons/ping. Replacement was in an intense radiation environment.
  - Preventing major beam loss is also very important for NuMI equipment protection.

Beam Instrumentation

- Primary beam instrumentation specifications will be covered in detail in a review to be held on **July 26**. A considerable motivation for the beam position instrumentation (non-interacting BPM's) and beam profile monitor (multi-wires) choices is to enable sustained high intensity operation for NuMI with minimal beam loss.
- Multi-wires will be used sparingly at high intensity, for a variety of functions:
  - precision beam position monitor calibration
  - beam profile diagnostics
  - calibration of beam loss monitors.

Sustained multi-wire use is precluded because of the beam loss generated, (see figure) and would also lead to degradation of MW performance.

- Loss monitors providing full geometrical coverage of beam loss - to a fractional loss sensitivity of $< 1 \cdot 10^{-5}$ - are essential components of primary beam instrumentation.

Vacuum System Parameters

- Primary transport vacuum system specifications are driven both by the need for low beam loss and the choice of beam instrumentation. Design parameters include:
  - The use of an isolation valve which will close based on vacuum pressure (several x 10^{-6} Torr) to separate Main Injector and NuMI vacuum systems.
  - No vacuum system windows are to be used.
  - System vacuum pressures of 10^{-5} Torr are needed to have minimal effect on beam loss levels. Similar pressure levels are needed for good function of the multi-wire and BPM's.
  - Specification of distributed ion pump systems provides the vacuum environment needed for reliable instrumentation function and low beam loss, as well as a robust low maintenance vacuum system. Use of ion pumps leads to vacuum levels of ~ 10^{-6} Torr.
- NuMI vacuum system choices are consistent with those for other beam transfer lines linking to the Main Injector.

Beam Loss Control

- Rigorous control of primary beam loss to a fractional loss level of $< 1 \cdot 10^{-4}$ has considerable impact on many of the primary system design specifications. Also included (besides instrumentation and vacuum system choices) are:
  - Larger magnet apertures - B-2's for major down-bend; 6-3-120's in Pre-target; open aperture for trim before carrier pipe.
  - Power supply stability requirements **(Review held on June 28)**
  - Auto-tune beam position control.
  - Comprehensive beam extraction permit and beam loss budget monitor systems. **(Review on August 17).**

Auto-tune Beam Control

- Automatic computer controlled correction of small (few mm) beam position excursions, using MI correctors and beam position monitors.
- Corrections are applied for the full beam line at one time, eliminating the beam loss during correction process which is common with manual beam tuning.
- Needs always active beam position instrumentation - BPM's.
  - More severe requirements on BPM function than for many applications.
- In previous usage of auto-tune beam control, computer controlled tuning was initiated when positions from nominal deviated by the following amounts:
  - Switchyard: along beam transport - 400 microns (0.4 mm)
    septa lineup - 200 microns (0.2 mm)
  - KTeV: along beam transport - 1000 microns (1.0 mm)
    target line-up - 50 microns (0.05 mm)
  - NuMI (projected): along beam transport - 1000 microns (1.0 mm)
    target line-up -250 microns (0.25 mm)

Beam Test Program

- Bunch rotation studies were carried out in summer of 2000 to verify (to first order) compatibility of combined operation - same MI cycle - for AP0 targeting and for NuMI.
- A broad-based test program is being initiated, using MI to P150 extraction, to understand and verify many MI beam parameters, beam stability and beam loss measurements, as well as prototyping for NuMI beam extraction permit system. Presentation by A. Marchionni.
- Power supply stability tests with similar ramp cycles and system loads to those for NuMI are being carried out on selected P150 supplies by D. Wolff and S. Hays.